NUMERICAL STUDIES PERTAINING TO AIRFLOW ON THE WEST COAST OF THE U.S. FY97 ANNUAL REPORT

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LONG-TERM GOALS:

An understanding of the origin and nature of the sudden transition in the local weather from clear skies to dense stratus clouds that often occurs during the spring and summer along the west coast of the U.S..

SCIENTIFIC OBJECTIVES:

To develop a correct fluid-dynamical understanding of the coastal flows that bring about such sudden transitions.

APPROACH:

Our working hypothesis is that the basic fluid-dynamics problem is one of a reservoir of relatively dense air (the marine layer), bounded by an insurmountable wall on one side (the coastal mountains of the U.S. west coast), under the influence of the Earth's rotation. Our approach is use a hierarchy of models of increasing complexity; in the case at hand, the two-dimensional (along-shore and cross-shore variation allowed) shallow-water equations (SWE) on an f-plane provide the minimal model. Primitive-equation models with simplified initial and boundary conditions provide the next step in our attempt to relate observational results to simple theoretical models.

WORK COMPLETED:

FY94: We developed a numerical model to solve the nonlinear SWE in generalized curvilinear coordinates on an f-plane. Under conditions of a straight coastline, we investigated problems in which the marine layer is initially: a) pent up by some unspecified agent, and then released, and b) in equilibrium, but subsequently subjected to an synoptic-scale pressure gradient.
Under conditions of a curved coastline, we investigated how wave motions and gravity currents behave as they propagate along a convex coastline.

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FY95: We have built a two-dimensional (x-z) nonhydrostatic primitive-equation model to complete our investigation of internal bores that form in the SWE Kelvin-wave solutions. We have built a three-dimensional nonhydrostatic primitive-equation (PE) model in terrain-following coordinates to examine in a more realistic context a) the mechanisms that produce the synoptic-scale pressure gradients that force the marine layer, and b) the effects of a more realistic medium on the propagation of the forced response.

We completed a paper on the convex-coastline problem (see FY 94), which was published in The Journal of the Atmospheric Sciences.

FY96: Based on extensive consultation with those analyzing the data from the 1994 ARI-sponsored field experiment, we have designed a relatively simple series of numerical experiments with the PE model developed in FY95. These experiments appear to capture all of the salient features found in the field data, yet due to the minimal number of physical elements included in the numerical experiments, a relatively simple physical interpretation of the numerical results can be made. Moreover side-by-side experiments with the nonlinear shallow water model developed in FY94, show that the essential elements of the phenomenon are contained in the latter.

We completed a paper on the propagation of internal bores (see the FY95 annual report), which was published in The Journal of Fluid Mechanics.

FY97: In the FY96 report we discussed numerical experiments with our PE model that appear to capture the basic elements of the observed chain of events that begins with a synoptic-scale disturbance and ends with the coastally trapped disturbance. This year we have worked to solidify the physical interpretation of the simulations.

A paper on this topic (Skamarock et al. 1997) is nearly complete.

SCIENTIFIC RESULTS:

Background:

The analyses of the results of the 1994 field program conducted under this ARI shows how changes on the synoptic scale lead to the small-scale coastally trapped disturbance [CTDs; see Ralph et al. 1996 (R96)]. Consistent with the climatology (Bond et al. 1996), R96 find the following: On the synoptic scale, the chain of events leading to a CTD begins with a ridging at 850 mb in the U.S. Pacific Northwest; concomitant with this ridging is an offshore-directed wind at the same level, but focused in central California (south of the ridge). R96 found that as the synoptic-scale wind turns offshore at 850 mb, the climatological northerly winds in the marine boundary layer also shift to an offshore direction south of Cape Mendocino, and that a mesoscale low-pressure feature develops at the coast and out to sea roughly between Monterey and Los Angeles. The mesoscale analysis of R96 suggests that the westward-shifted, southward-flowing marine boundary layer eventually turns cyclonically around the coastal mesoscale low-pressure feature, and therefore toward the coast near southern California; they hypothesize that the stable marine boundary layer then piles up at the coastal mountains, and the CTD is initiated. R96

present further evidence that the CTD observed on 10 June 1994 is consistent with a Kelvin wave, except that there is a more complex vertical structure than that of the one-layer shallow water equations.

Since the details of the PE simulations are described in the FY96 report, we reproduce here only the schematic summary of those simulations (Fig. 1). The observed climatological flow is represented as in Fig. 1a: There is northerly flow in the sloping marine boundary layer along a straight coast with steep mountains. The synoptic-scale perturbation to the climatological flow is represented in Fig. 1b with the development of anomalous high pressure to the north and low pressure to south. The geostrophic easterly wind implied by the synoptic pressure perturbation produces warming at the coast by advecting the sloping marine layer seaward, and through adiabatic compression of air flowing downslope. This warming produces a coastal mesoscale low pressure signal. In Fig 1c, the displaced northerly flow adjusts towards geostrophic balance with the low pressure associated with the depressed marine layer; when this flow turns eastward and encounters the coastal range, the marine layer piles up there and triggers a Kelvin-type wave that propagates northward toward, and eventually through, the center of the originally depressed marine layer.

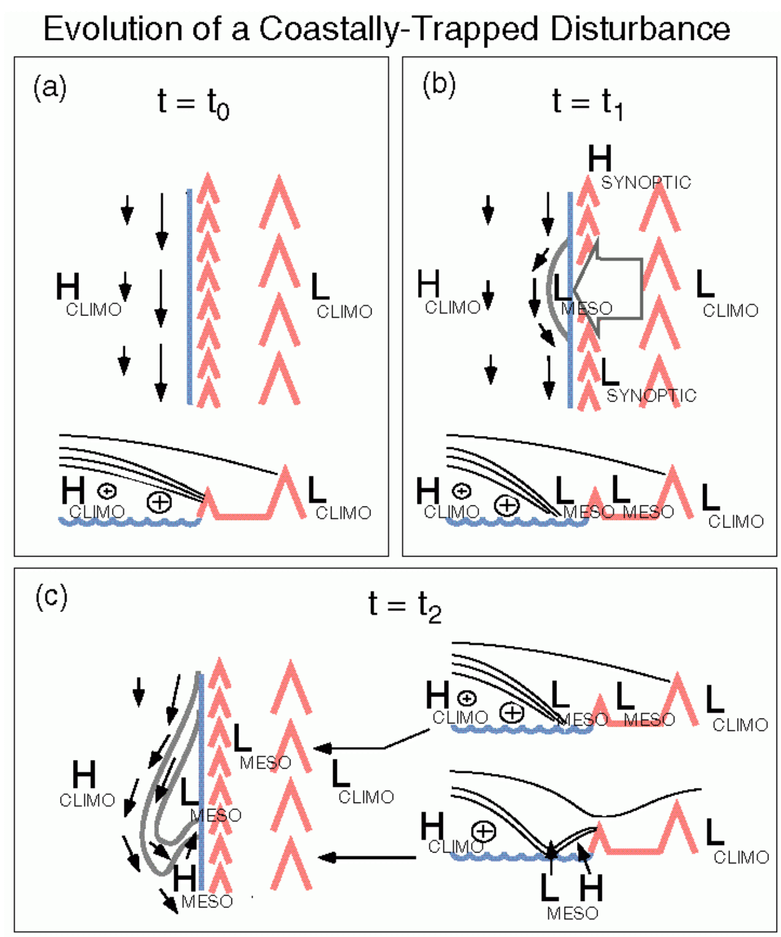

Figure 1: Summary of coastally-trapped disturbance evolution.

1. Through sensitivity testing and analysis, we have found that the stratification of the atmosphere above the marine layer supports a topographically trapped Rossby wave on the Sierras that can also act to progress signals northward (Fig. 2).

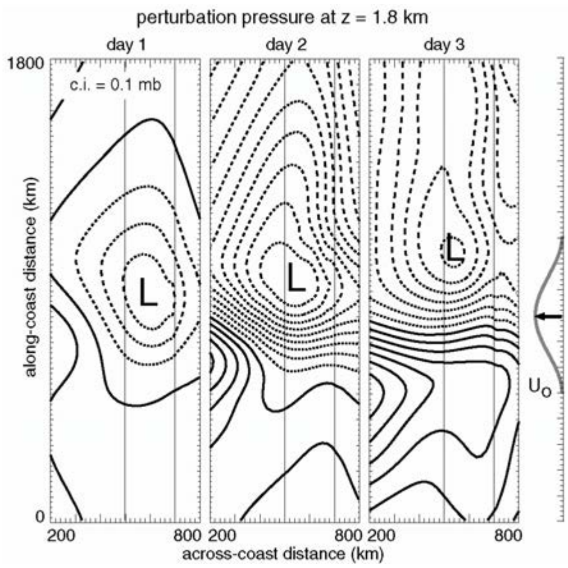

Figure 2: Topographically trapped Rossby wave signal observed in the perturbation pressure field. The terrain elevation rises from h=0 at x=500 km to h=1500 m at x=700 km, with the bottom and top of the plateau indicated by the thin solid lines.

2. Stratification above the marine layer implies that a Kelvin wave would lose energy through upward wave radiation. We have found that, for a sufficiently large amplitude Kelvin wave, nonlinear steepening of the wave front overcomes energy loss due to wave radiation, similar to the effect that internal energy dissipation has (Fig. 3).

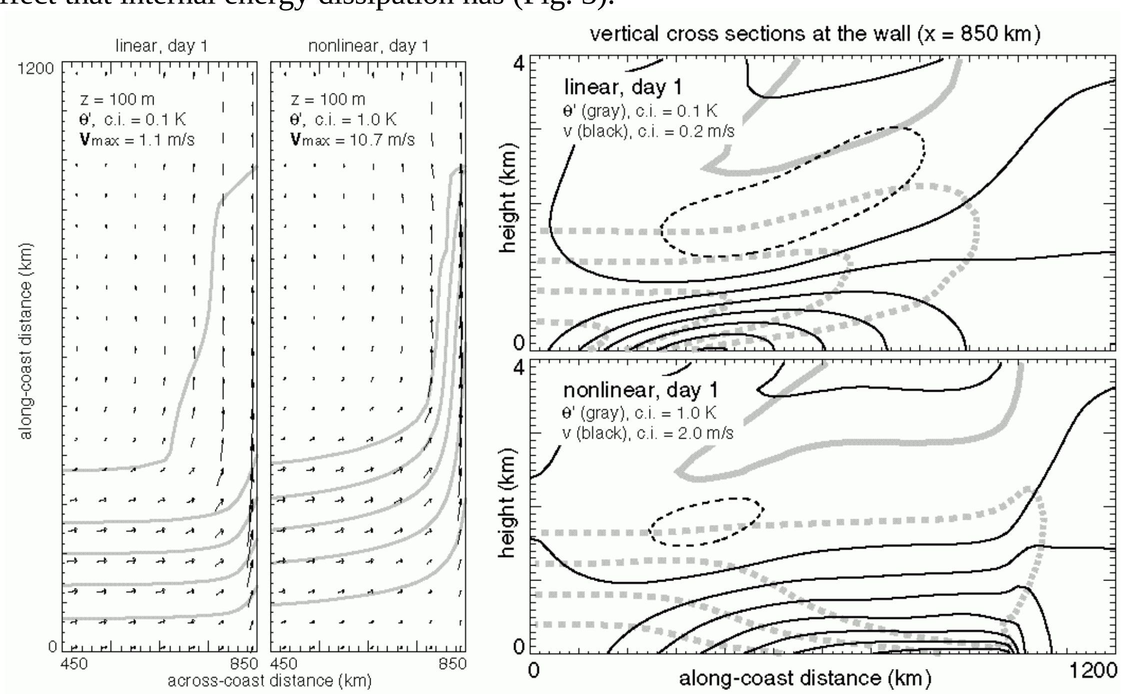

Figure 3: Horizontal and vertical cross sections from dambreak simulations with cold reservoirs having θ’ = .5 K (linear) and 5.K (nonlinear). The dam in the northward translating domain is located x=36 km at day 1.

IMPACT/APPLICATION:

1. We have solidified the physical interpretation of the minimal model presented in the FY96 report by investigating the role of stratification above the marine layer. This research should help in the development of improved forecasting schemes, and spur further research on the combined effects of topographically trapped Rossby waves and nonlinear Kelvin waves.

2. The topographically trapped waves found in our simulations of the CTD have substantial cross-coast penetration, and could conceivably explain the concurrent northward signal propagation observed hundreds of kilometers inland (e.g. Mass and Albright 1987). They also help explain the deep (4-6 km) penetration of the wind shift from northerly to southerly observed by R96.

3. The experiments suggesting that large amplitude Kelvin waves can be vertically trapped, even in an upbounded stratified fluid can help explain why it seems necessary that an amplitude threshold be crossed before a CTD that can propagate long distances is generated.

TRANSITIONS:

RELATED PROJECTS:

1. R. Samelson (WHOI) is investigating the effects of continuous stratification on a variety of linear Kelvin-wave models of CTDs.

2. M. Ralph (NOAA) and co-workers are working on analysis of the field data which motivated the design of our numerical experiments.

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